



(12) UK Patent (19) GB (11) 2 373 524 (13) B

(45) Date of publication: 21.04.2004

(54) Title of the invention: Lubricant coating for expandable tubular members

(51) Int Cl<sup>7</sup>: B23P 17/02, E21B 43/10

(21) Application No: 0208367.3

(22) Date of Filing: 05.10.2000

(30) Priority Data:  
(31) 60159039 (32) 12.10.1999 (33) US  
(31) 60165228 (32) 12.11.1999 (33) US

(60) Parent of Application No(s)  
0325071.9, 0325072.7 under Section 15(4) of  
the Patents Act 1977

(86) International Application Data:  
PCT/US2000/027645 En 05.10.2000

(87) International Publication Data:  
WO2001/026860 En 19.04.2001

(43) Date A Publication: 25.09.2002

(52) UK CL (Edition W ):  
E1F FLA

(56) Documents Cited:  
GB 2347952 A GB 2329916 A  
US 5368075 A US 4573248 A  
US 4413395 A US 4069573 A

(58) Field of Search:  
As for published application 2373524 A viz:  
Other: U.S. : 138/98; 29/890.031, 890.044  
updated as appropriate

(72) Inventor(s):  
Andrei Gregory Fillipov  
Mike Cowan  
William J Dean  
Lev Ring

(73) Proprietor(s):  
Enventure Global Technology  
(Incorporated in USA - Texas)  
2135 Highway 6 South, Houston,  
TX 77077, United States of America

(74) Agent and/or Address for Service:  
Haseltine Lake & Co  
Imperial House, 15-19 Kingsway,  
LONDON, WC2B 6UD, United Kingdom

BEST AVAILABLE COPY

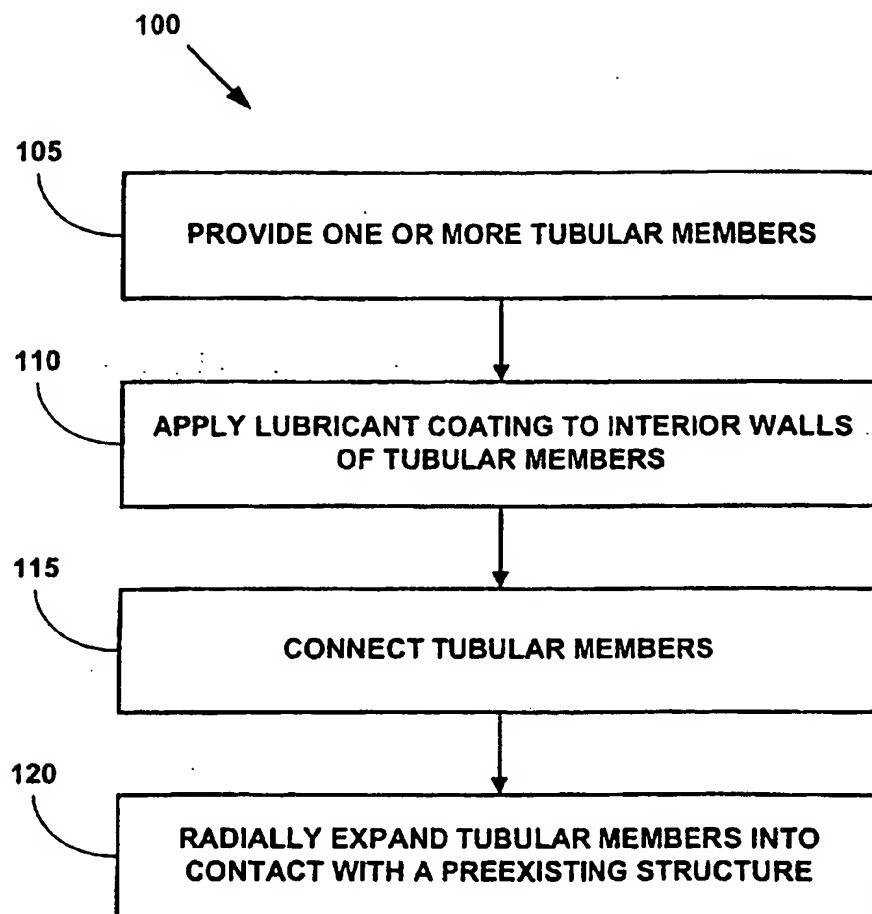


FIGURE 1

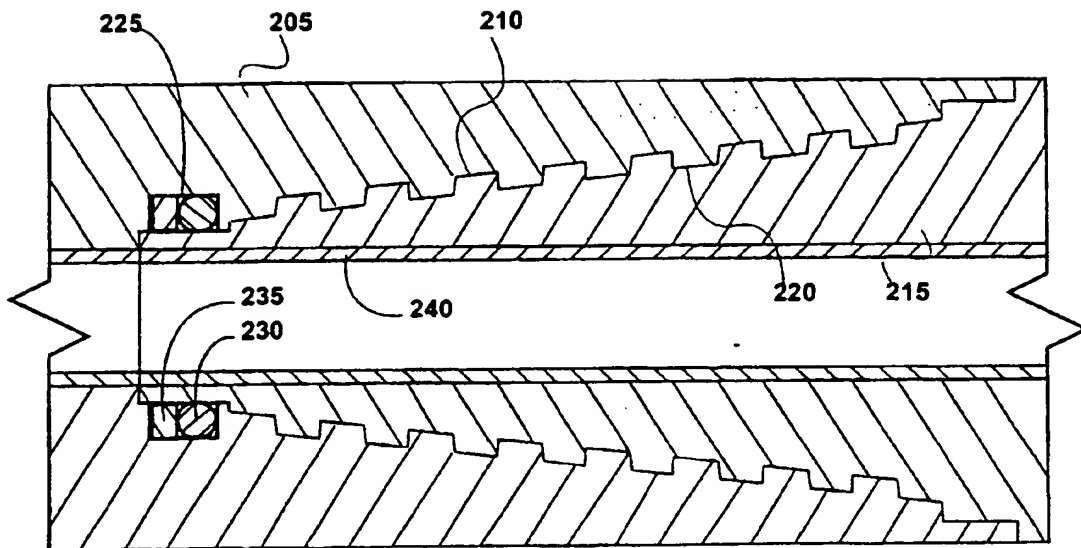


FIGURE 2

3/4

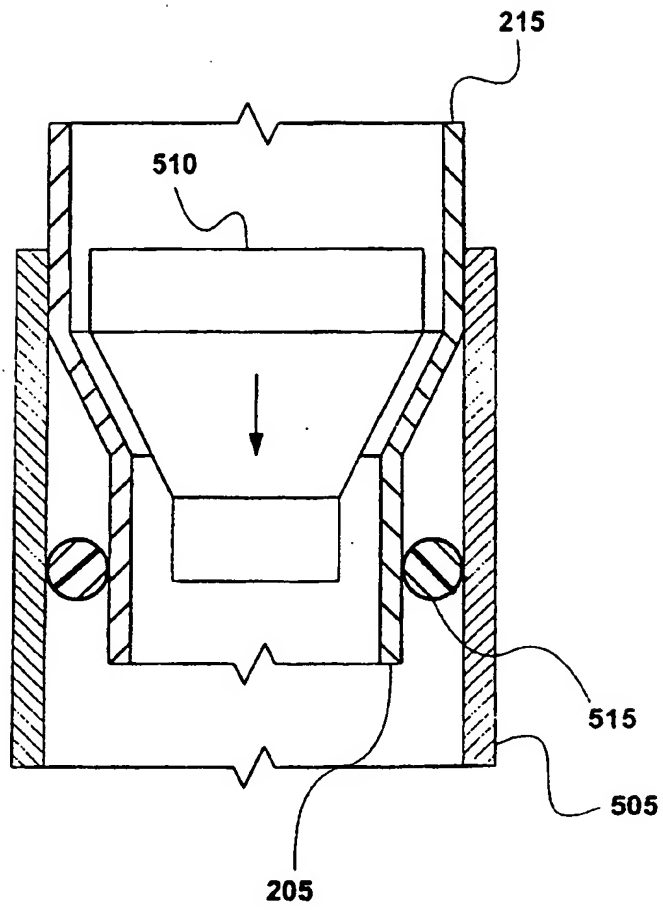


FIGURE 3

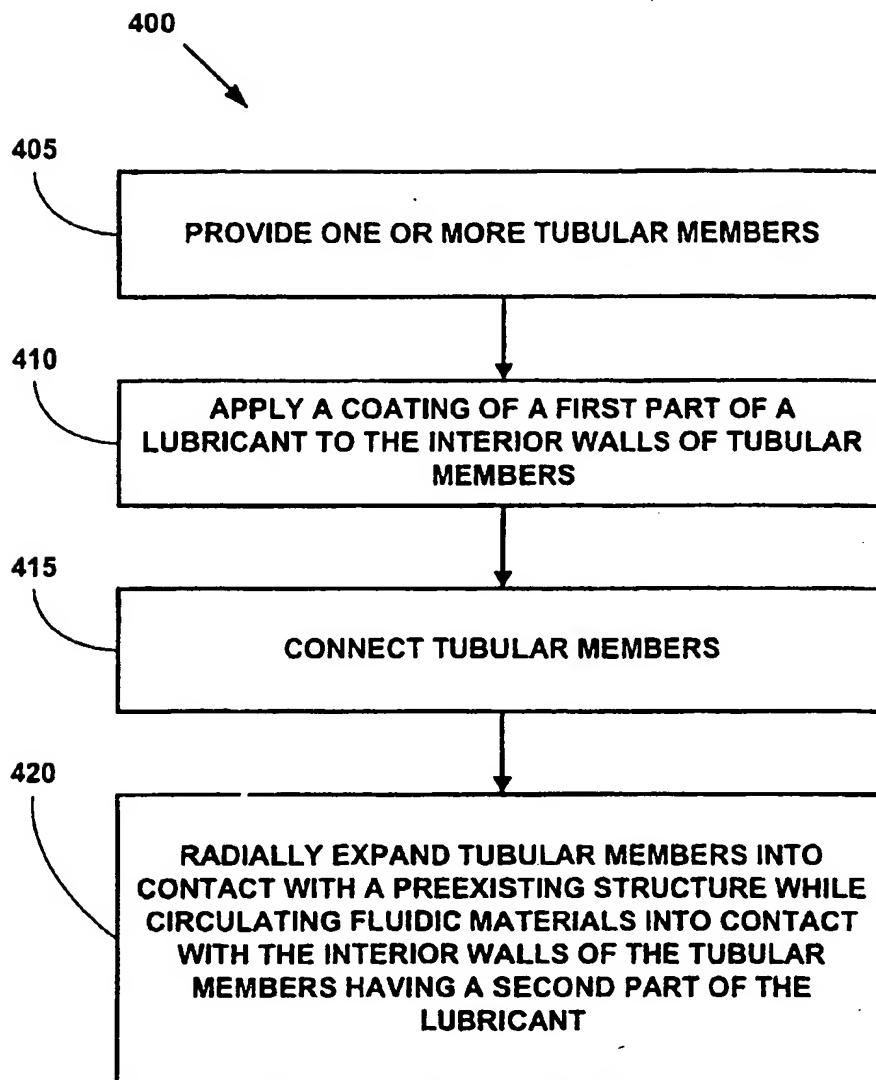


FIGURE 4

## LUBRICANT COATING FOR EXPANDABLE TUBULAR MEMBERS

### Background of the Invention

5        This invention relates generally to lubricant coating for expandable tubular members.

Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The  
10    borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are  
15    provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings.  
20    Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

The present invention is directed to overcoming one or more of the limitations of the existing procedures for forming wellbores.

### 25        Summary of the Invention

According to a first aspect of the present invention, there is provided an expandable tubular assembly, comprising:

- at least two tubular members coupled to one another; and
- a layer of a lubricant coupled to the interior surfaces of the tubular members.

30        According to a second aspect of the present invention, there is provided a method of coupling an expandable tubular assembly including one or more tubular members to a preexisting structure, comprising:

- coating the interior surfaces of the tubular members with a lubricant;
- then positioning the tubular members within a preexisting structure; and
- 35        then radially expanding the tubular members into contact with the preexisting structure.

According to a third aspect of the present invention, there is provided an apparatus, comprising:

a preexisting structure; and

one or more tubular members coupled to the preexisting structure by the process

5 of:

coating the interior surfaces of the tubular members with a lubricant;

then positioning the tubular members within a preexisting structure; and

then radially expanding the tubular members into contact with the preexisting structure.

10 According to a fourth aspect of the present invention, there is provided an expandable tubular assembly, comprising:

one or more tubular members; and

a layer of a first part of a lubricant coupled to the interior surfaces of the tubular members, the lubricant being chemically bonded, mechanically bonded, or adhesively  
15 bonded.

Preferably, the tubular members comprise wellbore casings.

Preferably, the tubular members comprise underground pipes.

Preferably, the tubular members comprise structural supports.

20 Preferably, the coating of lubricant is chemically bonded to the interior surfaces of the tubular members.

Preferably, the coating of lubricant is mechanically bonded to the interior surfaces of the tubular members.

Preferably, the coating of lubricant is adhesively bonded to the interior surfaces of the tubular members.

25 Preferably, the coating of lubricant includes:

a primer coating coupled to the interior surfaces of the tubular members; and

a coating of an antifriction paste coupled to the primer.

Preferably, the coating of lubricant includes, by weight:

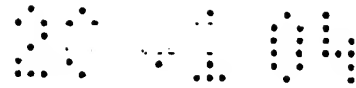
30 40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine.

Preferably, the coating of lubricant comprises a metallic soap.

Preferably, the coating of lubricant comprises zinc phosphate.

Preferably, the coating of lubricant provides a coefficient of dynamic friction of between 0.08 to 0.1.

35 Preferably, the coating of lubricant is selected from the group consisting of:



sodium stearates, calcium stearates, zinc stearates, zinc phosphate, manganese phosphate, polytetrafluoroethylene, molybdenum disulfide, and metallic soaps.

Preferably, the coating of lubricant provides a sliding coefficient of friction less than 0.20.

5        Preferably, the coating of lubricant is selected from the group consisting of:  
polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers, polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers, polyvinyl pyrrolidone and copolymers including polyolefins, latexes, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers for motor oils, polyacrylate esters, block copolymers including styrene, block copolymers including isoprene butadiene, block copolymers including ethylene, and ethylene acrylic acid copolymers.

15        Preferably, the coating of lubricant is selected from the group consisting of:  
graphite, molybdenum disulfide, lead powder, antimony oxide, polytetrafluoroethylene, and silicone polymers.

Preferably, the coating of lubricant comprises:

a solid lubricant; and

a binder.

20        Preferably, the binder is selected from the group consisting of:  
epoxy, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resin, acetone formaldehyde, phenolic, alkyd resins, and silicone modified alkyd resin.

Preferably, the binder is selected from the group consisting of:

25        vinyl acetate, vinyl chloride, maleic anhydride, maleic acid, ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers, and ethylene-vinyl acetate copolymers.

Preferably, the coating of lubricant comprises a suspension of particles in a carrier solvent.

30        Preferably, coating of lubricant is selected from the group consisting of:  
manganese phosphate, zinc phosphate, and iron phosphate.

Preferably, the coating of lubricant comprises 1 to 90 percent solids by volume.

Preferably, the coating of lubricant comprises 5 to 70 percent solids by volume.

Preferably, the coating of lubricant comprises 15 to 50 percent solids by volume.

Preferably, the coating of lubricant comprises:

35        5 to 80 percent graphite;

5 to 80 percent molybdenum disulfide;





1 to 40 percent PTFE; and

1 to 40 percent silicone polymers.

Preferably, the coating of lubricant comprises one or more of the following: ester; sulfurized oil; alkanolamides; amine; amine salt; olefin; polyolefins; C-8 to C-18 linear alcohol; derivatives of C-8 to C-18 linear alcohol including ester; derivatives of C-8 to C-18 linear alcohol including amine; derivatives of C-8 to C-18 linear alcohol including carboxylate; sulfonate; polyethylene glycol; silicone; siloxane; dinonyl phenol; ethylene oxide/ propylene oxide block copolymer.

10

#### Brief Description of the Drawings

For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

15 Fig. 1 is a flow chart illustrating a method for coupling a plurality of tubular members to a preexisting structure.

Fig. 2 is cross sectional illustration of a plurality of tubular members including in internal coating of a lubricant.

Fig. 3 is a fragmentary cross sectional illustration of the radial expansion of the tubular members of Fig. 2 into contact with a preexisting structure.

20 Fig. 4 is a flow chart illustrating a method for coupling a plurality of tubular members to a preexisting structure.

#### Detailed Description

In Fig. 1, a method 100 for forming and/or repairing a wellbore casing, pipeline, or structural support includes the steps of: (1) providing one or more tubular members in step 105; (2) applying a lubricant coating to the interior walls of the tubular members in step 110; (3) coupling the first and second tubular members in step 115; and (4) radially  
5 expanding the tubular members into contact with the preexisting structure in step 120.

As illustrated in Fig. 2, in step 105, a first tubular member 205 having a first threaded portion 210 and a second tubular member 215 having a second threaded portion 220 are provided. The first and second tubular members, 205 and 215, may be any number of conventional commercially available tubular members.

10 In step 110, a coating 240 of a lubricant is applied to the interior surfaces of the first and second tubular members, 205 and 215. The coating 240 of lubricant may be applied prior to, or after, the first and second tubular members, 205 and 215, are coupled. The coating 240 of lubricant may be applied using any number of conventional methods such as, for example, dipping, spraying, sputter coating or electrostatic deposition. The  
15 coating 240 of lubricant is chemically, mechanically, and/or adhesively bonded to the interior surfaces of the first and second tubular members, 205 and 215, in order to optimally provide a durable and consistent lubricating effect. The force that bonds the lubricant to the interior surfaces of the first and second tubular members, 205 and 215, is greater than the shear force applied during the radial expansion process.

20 The coating 240 of lubricant is applied to the interior surfaces of the first and second tubular members, 205 and 215, by first applying a phenolic primer to the interior surfaces of the first and second tubular members, 205 and 215, and then bonding the coating 240 of lubricant to the phenolic primer using an antifriction paste having the coating 240 of lubricant carried in an epoxy resin. The antifriction paste includes, by  
25 weight, 40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine. The antifriction paste is provided substantially as disclosed in U.S. Patent No. 4,329,238.

The coating 240 of lubricant may be any number of conventional commercially available lubricants such as, for example, metallic soaps or zinc phosphates. The coating  
30 240 of lubricant is compatible with conventional water, oil and synthetic base mud formulations. The coating 240 of lubricant reduces metal-to-metal frictional forces, operating pressures, reduces frictional forces by about 50%, and provides a coefficient of dynamic friction of between about 0.08 to 0.1 during the radial expansion process. The coating 240 of lubricant does not increase the toxicity of conventional base mud  
35 formulations and will not shear in synthetic mud. The coating 240 of lubricant is stable for

temperatures ranging from about -73.3°C to 260°C (-100 to 500 °F). The coating 240 of lubricant is stable when exposed to shear stresses. The coating 240 of lubricant is stable for storage periods of up to about 5 years. The coating 240 of lubricant provides corrosion protection for expandable tubular members during storage and transport.

5           The coating 240 of lubricant includes sodium, calcium, and/or zinc stearates; and/or zinc and/or manganese phosphates; and/or C-Lube-10 (registered trade mark); and/or C-Phos-58-M (registered trade mark); and/or C-Phos-58-R (registered trade mark); and/or polytetrafluoroethylene (PTFE); and/or molybdenum disulfide; and/or metallic soaps (stearates, oleates, etc ...) in order to optimally provide a coating of lubricant. The  
10       coating 240 of lubricant provides a sliding coefficient of friction less than about 0.20 in order to optimally reduce the force required to radially expand the tubular members, 205 and 215, using an expansion cone.

          In step 115, the first and second tubular members, 205 and 215, are coupled. The first and second tubular members, 205 and 215, may be coupled using a threaded  
15       connection, or, alternatively, the first and second tubular members, 205 and 215, may be coupled by welding or brazing. The first and second tubular members, 205 and 215, are coupled substantially as disclosed in provisional patent application serial number 60/159,033, attorney docket number 25791.37, filed on October 12, 1999.

          As illustrated in Fig. 3, in steps 120, the first and second tubular members 205  
20       and 215 are then positioned within a preexisting structure 505, and radially expanded into contact with the interior walls of the preexisting structure 505 using an expansion cone 510. The tubular members 205 and 215 may be radially expanded into intimate contact with the interior walls of the preexisting structure 505, for example, by: (1) pushing or pulling the expansion cone 510 through the interior of the tubular members 205 and 215;  
25       and/or (2) pressurizing the region within the tubular members 205 and 215 behind the expansion cone 510 with a fluid. One or more sealing members 515 are further provided on the outer surface of the tubular members 205 and 215, in order to optimally seal the interface between the radially expanded tubular members 205 and 215 and the interior walls of the preexisting structure 505.

30           As illustrated in Fig. 4, a method 400 for forming and/or repairing a wellbore casing, pipeline, or structural support includes the steps of: (1) providing one or more tubular members in step 405; (2) applying a coating including a first part of a lubricant to the interior walls of the tubular members in step 410; (3) coupling the first and second tubular members in step 415; and (4) radially expanding the tubular members into contact  
35       with the preexisting structure while also circulating fluidic materials into contact with the interior walls of the tubular members having a second part of the lubricant in step 420.

In step 410, a coating including a first part of a lubricant is applied to the interior walls of the tubular members, 205 and 215. The first part of the lubricant forms a first part of a metallic soap. The first part of the lubricant coating includes zinc phosphate.

5 In step 420, a second part of the lubricant is circulated within a fluidic carrier into contact with the coating of the first part of the lubricant applied to the interior walls of the tubular members, 205 and 215. The first and second parts react to form a lubricating layer between the interior walls of the tubular members, 205 and 215, and the exterior surface of the expansion cone. In this manner, a lubricating layer is provided in exact concentration, exactly when and where it is needed. Furthermore, because the second  
10 part of the lubricant is circulated in a carrier fluid, the dynamic interface between the interior surfaces of the tubular members, 205 and 215, and the exterior surface of the expansion cone 510 is also preferably provided with hydrodynamic lubrication. The first and second parts of the lubricant react to form a metallic soap. The second part of the lubricant is sodium, calcium and/or zinc stearate.

15 In several experimental operations of the methods 100 and 400, the following observations were made regarding lubricant coatings for expandable tubular members:

- (1) boundary lubrication with a lubricant coating having high adhesion (high film/shear strength) to the expandable tubular is the single-most important lubricant/lubrication process in the radial expansion process;
- 20 (2) hydrodynamic lubrication plays a secondary role in the lubrication process;
- (3) expandable tubular lubricant coating offers the more reliable and more effective form of boundary lubrication;
- (4) a liquid lubricant viscosity and/or film strength that provides effective,  
25 consistent boundary lubrication typically limits the effectiveness of additives for the mud alone to provide the necessary lubrication while maintaining drilling fluid properties (rheology, toxicity);
- (5) consistent reductions of 20 to 25 percent in propagation force during the radial expansion process (compared to uncoated expandable tubular control results) were obtained with the following dry film coatings: (1) polytetrafluoroethylene (PTFE), (2) molybdenum disulfide, and (3) metallic soap (stearates), these results are for laboratory tests on one inch dry  
30 pipe, in the absence of any drilling fluid;
- (6) a 20 to 25 percent reduction in propagation force during the radial  
35 expansion process was observed;

- (7) synthetic oil muds do not typically provide sufficient, reliable lubrication for uncoated pipe;
- (8) the coefficient of friction for expandable tubular lubricant coatings remains essentially constant across a wide temperature range;
- 5 (9) the expected application range for expandable tubular casing expansion is between 4.4°C and 204.4°C (40 °F and 400 °F), this range is well within the essentially constant range for coefficient of friction for good coatings; and
- 10 (10) good extreme pressure boundary lubricants have a characteristic of performing better (lower coefficients of friction) as the load increases, coefficients of friction between 0.02 and 0.08 are reported for some coatings.

The optimum lubrication for in-situ expandable tubular radial expansion operations using the methods 100 and/or 400 includes a combination of lubrication techniques and lubricants. These can be summarized as follows: (1) extreme pressure lubricants/lubrication techniques; and (2) hydrodynamic lubrication from the fluid in the pipe during expansion.

Extreme pressure lubrication is preferably provided by: (1) liquid extreme pressure lubricants added to the fluid (e.g., drilling fluid, etc) in contact with the internal surface of the expandable tubular during the radial expansion process, and/or (2) solid lubricants added to the fluid added to, or contained within, the fluid in contact with the internal surface of the expandable tubular member during the radial expansion process, and/or (3) solid lubricants applied to the internal surface of the expandable tubular member to be radially expanded, and/or (4) combinations of (1), (2) and (3) above.

25 Liquid extreme pressure lubricant additives preferably work by chemically adhering to or being strongly attracted to the surface of the expandable tubular to be expanded. These types of liquid extreme pressure lubricant additives preferably form a 'film' on the surface of the expandable tubular member. The adhesive strength of this film is preferably greater than the shearing force along the internal surface of the expandable tubular member during the radial expansion process. This adhesive force is referred to as film strength. The film strength can be increased by increasing the viscosity of the fluid. Common viscosifiers, such as polymeric additives, are preferably added to the fluid in contact with the internal surface of the expandable tubular member during the radial expansion process to increase lubrication. These liquid extreme pressure lubricant additives include one or more of the following: polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives such as, for example, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers,

35

polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers, polyvinyl pyrrolidone and copolymers including polyolefins, latexes such as, for example, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers for motor oils such as polyacrylate esters, block copolymers including styrene, isoprene butadiene and ethylene, ethylene acrylic acid copolymers.

Extreme pressure lubrication is provided using solid lubricants that are applied to the internal surface of the expandable tubular member. These solid lubricants can be applied using various conventional methods of applying a film to a surface. These solid lubricants are applied in a manner that ensures that the solid lubricants remain on the surface of the expandable tubular member during installation and radial expansion of the expandable tubular member. The solid lubricants preferably include one or more of the following: graphite, molybdenum disulfide, lead powder, antimony oxide, poly tetrafluoroethylene (PTFE), or silicone polymers. Furthermore, blends of these solid lubricants are preferred.

The solid lubricants are applied directly to the expandable tubulars as coatings. The coating of the solid lubricant preferably includes a binder to help hold or fix the solid lubricant to the expandable tubular. The binders preferably include curable resins such as, for example, epoxies, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resins, acetone formaldehyde, phenolic, alkyd resins, silicone modified alkyd resins, etc. The binder is preferably selected to withstand the expected temperature range, pH, salinity and fluid types during the installation and radial expansion operations. Polymeric materials are preferably used to bind the solid lubricants to the expandable tubular such as, for example, "self-adhesive" polymers such as those copolymers or terpolymers based upon vinyl acetate, vinyl chloride, maleic anhydride/maleic acid, and ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers and ethylene-vinyl acetate copolymers. The solid lubricants are applied as suspensions of fine particles in a carrier solvent without the presence/use of a chemical binder.

The solid lubricant coating and the liquid lubricant additive (added to the fluid in contact with the internal surface of the expandable tubular member during the radial expansion process) interact during the radial expansion process to improve the overall lubrication. For phosphate solid lubricant coatings, manganese phosphate is preferred over zinc or iron phosphate because it more effectively attracts and retains liquid lubricant additives such as oils, esters, amides, etc.

Solid lubricant coatings use binders that provide low friction that is enhanced under extreme pressure conditions by the presence of the solid lubricant. Solid lubricant coatings includes one or more of the following: graphite, molybdenum disulfide, silicone

polymers and polytetrafluoroethylene (PTFE). Blends of these materials are used since each material has lubrication characteristics that optimally work at different stages in the radial expansion process. A solid, dry film lubricant coating for the internal surface of the expandable tubular includes: (1) 1 to 90 percent solids by volume; (2) more preferably, 5 to 70 percent solids by volume; and (3) most preferably, 15 to 50 percent solids by volume. The solid lubricants include: (1) 5 to 80 percent graphite; (2) 5 to 80 percent molybdenum disulfide; (3) 1 to 40 percent PTFE; and (4) 1 to 40 percent silicone polymers.

The liquid lubricant additives include one or more of the following: (1) esters including: (a) organic acid esters (preferably fatty acid esters) such as, for example, trimethylol propane, isopropyl, penterithritol, n-butyl, etc.; (b) glycerol tri(acetoxy stearate) and N,N' ethylene bis 12 hydroxystearate and octyl hydroxystearate; (c) phosphate and phosphite such as, for example, butylated triphenyl phosphate and isodiphenyl phosphate; (2) sulfurized natural and synthetic oils; (3) alkanolamides such as, for example, coco diethanolamide; (4) amines and amine salts; (5) olefins and polyolefins; (6) C-8 to C-18 linear alcohols and derivatives containing or consisting of esters, amines, carboxylates, etc.; (7) overbased sulfonates such as, for example, calcium sulfonate, sodium sulfonate, magnesium sulfonate; (8) polyethylene glycols; (9) silicones and siloxanes such as, for example, dimethylpolysiloxanes and fluorosilicone derivatives; (10) dinonyl phenols; and (11) ethylene oxide/propylene oxide block copolymers.

Although this detailed description has shown and described illustrative embodiments of the invention, this description contemplates a wide range of modifications, changes, and substitutions. In some instances, one may employ some features of the present invention without a corresponding use of the other features. Accordingly, it is appropriate that readers should construe the appended claims broadly, and in a manner consistent with the scope of the invention.

## Claims

1. An expandable tubular assembly, comprising:  
at least two tubular members coupled to one another; and  
5 a layer of a lubricant coupled to the interior surfaces of the tubular members.
2. A method of coupling an expandable tubular assembly including one or more tubular members to a preexisting structure, comprising:  
coating the interior surfaces of the tubular members with a lubricant;  
10 then positioning the tubular members within a preexisting structure; and  
then radially expanding the tubular members into contact with the preexisting structure.
3. An apparatus, comprising:  
15 a preexisting structure; and  
one or more tubular members coupled to the preexisting structure by the process of:  
coating the interior surfaces of the tubular members with a lubricant;  
then positioning the tubular members within a preexisting structure; and  
20 then radially expanding the tubular members into contact with the preexisting structure.
4. An expandable tubular assembly, comprising:  
one or more tubular members; and  
25 a layer of a first part of a lubricant coupled to the interior surfaces of the tubular members, the lubricant being chemically bonded, mechanically bonded, or adhesively bonded.
5. The expandable tubular assembly of claim 1, wherein the tubular members  
30 comprise wellbore casings.
6. The expandable tubular assembly of claim 1, wherein the tubular members comprise underground pipes.
- 35 7. The expandable tubular assembly of claim 1, wherein the tubular members comprise structural supports.



8. The expandable tubular assembly of claim 1, wherein the coating of lubricant is chemically bonded to the interior surfaces of the tubular members.
- 5 9. The expandable tubular assembly of claim 1, wherein the coating of lubricant is mechanically bonded to the interior surfaces of the tubular members.
- 10 10. The expandable tubular assembly of claim 1, wherein the coating of lubricant is adhesively bonded to the interior surfaces of the tubular members.
- 10 11. The expandable tubular assembly of claim 1, wherein the coating of lubricant includes:
  - a primer coating coupled to the interior surfaces of the tubular members; and
  - a coating of an antifriction paste coupled to the primer.
- 15 12. The expandable tubular assembly of claim 1, wherein the coating of lubricant includes, by weight:
  - 40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine.
- 20 13. The expandable tubular assembly of claim 1, wherein the coating of lubricant comprises a metallic soap.
14. The expandable tubular assembly of claim 1, wherein the coating of lubricant
- 25 15. The expandable tubular assembly of claim 1, wherein the coating of lubricant provides a coefficient of dynamic friction of between 0.08 to 0.1.
- 30 16. The expandable tubular assembly of claim 1, wherein the coating of lubricant is selected from the group consisting of:
  - sodium stearates, calcium stearates, zinc stearates, zinc phosphate, manganese phosphate, polytetrafluoroethylene, molybdenum disulfide, and metallic soaps.
- 35 17. The expandable tubular assembly of claim 1, wherein the coating of lubricant provides a sliding coefficient of friction less than 0.20.

18. The expandable tubular assembly of claim 1, wherein the coating of lubricant is selected from the group consisting of:
- polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers, polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers, polyvinyl pyrrolidone and copolymers including polyolefins, latexes, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers for motor oils, polyacrylate esters, block copolymers including styrene, block copolymers including isoprene butadiene, block copolymers including ethylene, and ethylene acrylic acid copolymers.
19. The expandable tubular assembly of claim 1, wherein the coating of lubricant is selected from the group consisting of:
- graphite, molybdenum disulfide, lead powder, antimony oxide, polytetrafluoroethylene, and silicone polymers.
20. The expandable tubular assembly of claim 1, wherein the coating of lubricant comprises:
- a solid lubricant; and  
a binder.
21. The expandable tubular assembly of claim 20, wherein the binder is selected from the group consisting of:
- epoxy, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resin, acetone formaldehyde, phenolic, alkyd resins, and silicone modified alkyd resin.
22. The expandable tubular assembly of claim 20, wherein the binder is selected from the group consisting of:
- vinyl acetate, vinyl chloride, maleic anhydride, maleic acid, ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers, and ethylene-vinyl acetate copolymers.
23. The expandable tubular assembly of claim 1, wherein the coating of lubricant comprises a suspension of particles in a carrier solvent.

24. The expandable tubular assembly of claim 1, the coating of lubricant is selected from the group consisting of:  
manganese phosphate, zinc phosphate, and iron phosphate.
- 5 25. The expandable tubular assembly of claim 1, wherein the coating of lubricant comprises:  
1 to 90 percent solids by volume.
26. The expandable tubular assembly of claim 25, wherein the coating of lubricant  
10 comprises:  
5 to 70 percent solids by volume.
27. The expandable tubular assembly of claim 26, wherein the coating of lubricant  
15 comprises:  
15 to 50 percent solids by volume.
28. The expandable tubular assembly of claim 1, wherein the coating of lubricant  
comprises:  
20 5 to 80 percent graphite;  
5 to 80 percent molybdenum disulfide;  
1 to 40 percent PTFE; and  
1 to 40 percent silicone polymers.
29. The expandable tubular assembly of claim 1, wherein the coating of lubricant  
25 comprises one or more of the following: ester; sulfurized oil; alkanolamides; amine; amine  
salt; olefin; polyolefins; C-8 to C-18 linear alcohol; derivatives of C-8 to C-18 linear  
alcohol including ester; derivatives of C-8 to C-18 linear alcohol including amine;  
derivatives of C-8 to C-18 linear alcohol including carboxylate; sulfonate; polyethylene  
glycol; silicone; siloxane; dinonyl phenol; and ethylene oxide/propylene oxide block  
30 copolymer.
30. The method of claim 2, wherein the tubular members comprise wellbore casings.
31. The method of claim 2, wherein the tubular members comprise underground  
35 pipes.

32. The method of claim 2, wherein the tubular members comprise structural supports.
33. The method of claim 2, wherein the coating of lubricant is chemically bonded to the interior surfaces of the tubular members.
34. The method of claim 2, wherein the coating of lubricant is mechanically bonded to the interior surfaces of the tubular members.
35. The method of claim 2, wherein the coating of lubricant is adhesively bonded to the interior surfaces of the tubular members.
36. The method of claim 2, wherein the coating of lubricant includes:  
a primer coating coupled to the interior surfaces of the tubular members; and  
a coating of an antifriction paste coupled to the primer.
37. The method of claim 2, wherein the coating of lubricant includes, by weight:  
40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine.
38. The method of claim 2, wherein the coating of lubricant comprises a metallic soap.
39. The method of claim 2, wherein the coating of lubricant comprises zinc phosphate.
40. The method of claim 2, wherein the coating of lubricant provides a coefficient of dynamic friction of between 0.08 to 0.1.
41. The method of claim 2, wherein the coating of lubricant is selected from the group consisting of:  
sodium stearates, calcium stearates, zinc stearates, zinc phosphate, manganese phosphate, polytetrafluoroethylene, molybdenum disulfide, and metallic soaps.
42. The method of claim 2, wherein the coating of lubricant provides a sliding coefficient of friction less than 0.20.

43. The method of claim 2, wherein the coating of lubricant is selected from the group consisting of:  
polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers, polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers, polyvinyl pyrrolidone and copolymers including polyolefins, latexes, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers for motor oils, polyacrylate esters, block copolymers including styrene, block copolymers including isoprene butadiene, block copolymers including ethylene, and ethylene acrylic acid copolymers.
44. The method of claim 2, wherein the coating of lubricant is selected from the group consisting of:  
graphite, molybdenum disulfide, lead powder, antimony oxide, polytetrafluoroethylene, and silicone polymers.
45. The method of claim 2, wherein the coating of lubricant comprises:  
a solid lubricant; and  
a binder.
46. The method of claim 45, wherein the binder is selected from the group consisting of:  
epoxy, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resin, acetone formaldehyde, phenolic, alkyd resins, and silicone modified alkyd resin.
47. The method of claim 45, wherein the binder is selected from the group consisting of:  
vinyl acetate, vinyl chloride, maleic anhydride, maleic acid, ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers, and ethylene-vinyl acetate copolymers.
48. The method of claim 2, wherein the coating of lubricant comprises a suspension of particles in a carrier solvent.
49. The method of claim 2, wherein the coating of lubricant is selected from the group consisting of:

manganese phosphate, zinc phosphate, and iron phosphate.

50. The method of claim 2, wherein the coating of lubricant comprises:  
1 to 90 percent solids by volume.
- 5
51. The method of claim 50, wherein the coating of lubricant comprises:  
5 to 70 percent solids by volume.
52. The method of claim 51, wherein the coating of lubricant comprises:  
15 to 50 percent solids by volume.
- 10
53. The method of claim 2, wherein the coating of lubricant comprises:  
5 to 80 percent graphite;  
5 to 80 percent molybdenum disulfide;  
1 to 40 percent PTFE; and  
1 to 40 percent silicone polymers.
- 15
54. The method of claim 2, wherein the coating of lubricant comprises one or more of  
the following: ester; sulfurized oil; alkanolamides; amine; amine salt; olefin; polyolefins; C-  
8 to C-18 linear alcohol; derivative of C-8 to C-18 linear alcohol including ester; derivative  
of C-8 to C-18 linear alcohol including amine; derivative of C-8 to C-18 linear alcohol  
including carboxylate; sulfonate; polyethylene glycol; silicone; siloxane; dinonyl phenol;  
and ethylene oxide/propylene oxide block copolymer.
- 20
55. The apparatus of claim 3, wherein the tubular members comprise wellbore  
casings.
- 25
56. The apparatus of claim 3, wherein the tubular members comprise underground  
pipes.
- 30
57. The apparatus of claim 3, wherein the tubular members comprise structural  
supports.
58. The apparatus of claim 3, wherein the coating of lubricant is chemically bonded to  
the interior surfaces of the tubular members.
- 35

59. The apparatus of claim 3, wherein the coating of lubricant is mechanically bonded to the interior surfaces of the tubular members.
60. The apparatus of claim 3, wherein the coating of lubricant is adhesively bonded to the interior surfaces of the tubular members.
61. The apparatus of claim 3, wherein the coating of lubricant includes:  
a primer coating coupled to the interior surfaces of the tubular members; and  
a coating of an antifriction paste coupled to the primer.
62. The apparatus of claim 3, wherein the coating of lubricant includes, by weight:  
40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine.
63. The apparatus of claim 3, wherein the coating of lubricant comprises a metallic soap.
64. The apparatus of claim 3, wherein the coating of lubricant comprises zinc phosphate.
65. The apparatus of claim 3, wherein the coating of lubricant provides a coefficient of dynamic friction of between 0.08 to 0.1.
66. The apparatus of claim 3, wherein the coating of lubricant is selected from the group consisting of:  
sodium stearates, calcium stearates, zinc stearates, zinc phosphate, manganese phosphate, polytetrafluoroethylene, molybdenum disulfide, and metallic soaps.
67. The apparatus of claim 3, wherein the coating of lubricant provides a sliding coefficient of friction less than 0.20.
68. The apparatus of claim 3, wherein the coating of lubricant is selected from the group consisting of:  
polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers, polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers,

polyvinyl pyrrolidone and copolymers including polyolefins, latexes, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers for motor oils, polyacrylate esters, block copolymers including styrene, block copolymers including isoprene butadiene, block copolymers including ethylene, and ethylene acrylic acid copolymers.

69. The apparatus of claim 3, wherein the coating of lubricant is selected from the group consisting of:

graphite, molybdenum disulfide, lead powder, antimony oxide, polytetrafluoroethylene, and silicone polymers.

70. The apparatus of claim 3, wherein the coating of lubricant comprises: a solid lubricant; and a binder.

71. The apparatus of claim 70, wherein the binder is selected from the group consisting of:

epoxy, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resin, acetone formaldehyde, phenolic, alkyd resins, and silicone modified alkyd resin.

72. The apparatus of claim 70, wherein the binder is selected from the group consisting of:

vinyl acetate, vinyl chloride, maleic anhydride, maleic acid, ethylene-acrylic acid copolymers, ethylene-methacrylic acid copolymers, and ethylene-vinyl acetate copolymers.

73. The apparatus of claim 3, wherein the coating of lubricant comprises a suspension of particles in a carrier solvent.

74. The apparatus of claim 3, the coating of lubricant is selected from the group consisting of:

manganese phosphate, zinc phosphate, and iron phosphate.

75. The apparatus of claim 3, wherein the coating of lubricant comprises: 1 to 90 percent solids by volume.



76. The apparatus of claim 75, wherein the coating of lubricant comprises:  
5 to 70 percent solids by volume.
77. The apparatus of claim 76 wherein the coating of lubricant comprises:  
15 to 50 percent solids by volume.
78. The apparatus of claim 3, wherein the coating of lubricant comprises:  
5 to 80 percent graphite;  
5 to 80 percent molybdenum disulfide;  
1 to 40 percent PTFE; and  
1 to 40 percent silicone polymers.
79. The apparatus of claim 3, wherein the coating of lubricant comprises one or more  
of the following: ester; sulfurized oil; alkanolamides; amine; amine salt; olefin; polyolefins;  
C-8 to C-18 linear alcohol; derivative of C-8 to C-18 linear alcohol including ester;  
derivative of C-8 to C-18 linear alcohol including amine; derivative of C-8 to C-18 linear  
alcohol including carboxylate; sulfonate; polyethylene glycol; silicone; siloxane; dinonyl  
phenol; and ethylene oxide/propylene oxide block copolymer.
80. The expandable tubular assembly of claim 4, wherein the tubular members  
comprise wellbore casings.
81. The expandable tubular assembly of claim 4, wherein the tubular members  
comprise underground pipes.
82. The expandable tubular assembly of claim 4, wherein the tubular members  
comprise structural supports.
83. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
the lubricant is chemically bonded to the interior surfaces of the tubular members.
84. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
the lubricant is mechanically bonded to the interior surfaces of the tubular members.
85. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
the lubricant is adhesively bonded to the interior surfaces of the tubular members.

86. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant includes:
- 5 a primer coating coupled to the interior surfaces of the tubular members; and  
a coating of an antifriction paste coupled to the primer.
87. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant includes, by weight:
- 10 40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% aluminosilicate, and 5-10% polyethylenepolyamine.
88. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant comprises a metallic soap.
- 15 89. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant comprises zinc phosphate.
90. The expandable tubular assembly of claim 4, wherein the lubricant provides a coefficient of dynamic friction of between 0.08 to 0.1.
- 20 91. The expandable tubular assembly of claim 4, wherein the lubricant is selected from the group consisting of:
- sodium stearates, calcium stearates, zinc stearates, zinc phosphate, manganese phosphate, polytetrafluoroethylene, molybdenum disulfide, and metallic soaps.
- 25 92. The expandable tubular assembly of claim 4, wherein the lubricant provides a sliding coefficient of friction less than 0.20.
93. The expandable tubular assembly of claim 4, wherein the lubricant is selected from the group consisting of:
- 30 polyacrylamide polymers, AMPS-acrylamide copolymers, modified cellulose derivatives, hydroxyethylcellulose, carboxymethyl hydroxyethyl cellulose, polyvinyl alcohol polymers, polyvinyl acetate polymers, polyvinyl alcohol/vinyl acetate copolymers, polyvinyl pyrrolidone and copolymers including polyolefins, latexes, styrene butadiene latex, urethane latexes, styrene-maleic anhydride copolymers, viscosity index improvers
- 35 for motor oils, polyacrylate esters, block copolymers including styrene, block copolymers

including isoprene butadiene, block copolymers including ethylene, and ethylene acrylic acid copolymers.

94. The expandable tubular assembly of claim 4, wherein the lubricant is selected  
5 from the group consisting of:  
graphite, molybdenum disulfide, lead powder, antimony oxide, poly  
tetrafluoroethylene, and silicone polymers.
95. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
10 the lubricant comprises:  
a solid lubricant; and  
a binder.
96. The expandable tubular assembly of claim 95, wherein the binder is selected from  
15 the group consisting of:  
epoxy, acrylic, urea-formaldehyde, melamine formaldehyde, furan based resin,  
acetone formaldehyde, phenolic, alkyd resins, and silicone modified alkyd resin.
97. The expandable tubular assembly of claim 95, wherein the binder is selected from  
20 the group consisting of:  
vinyl acetate, vinyl chloride, maleic anhydride, maleic acid, ethylene-acrylic acid  
copolymers, ethylene-methacrylic acid copolymers, and ethylene-vinyl acetate  
copolymers.
98. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
25 the lubricant comprises a suspension of particles in a carrier solvent.
99. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
the lubricant is selected from the group consisting of:  
30 manganese phosphate, zinc phosphate, and iron phosphate.
100. The expandable tubular assembly of claim 4, wherein the layer of the first part of  
the lubricant comprises:  
1 to 90 percent solids by volume.

35

101. The expandable tubular assembly of claim 100, wherein the layer of the first part of the lubricant comprises:

5 to 70 percent solids by volume.

5 102. The expandable tubular assembly of claim 101, wherein the layer of the first part of the lubricant comprises:

15 to 50 percent solids by volume.

10 103. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant comprises:

5 to 80 percent graphite;

5 to 80 percent molybdenum disulfide;

1 to 40 percent PTFE; and

1 to 40 percent silicone polymers.

15

104. The expandable tubular assembly of claim 4, wherein the layer of the first part of the lubricant comprises one or more of the following: ester; sulfurized oil; alkanolamides; amine; amine salt; olefin; polyolefins; C-8 to C-18 linear alcohol; derivatives of C-8 to C-18 linear alcohol including ester; derivatives of C-8 to C-18 linear alcohol including amine; derivatives of C-8 to C-18 linear alcohol including carboxylate; sulfonate; polyethylene glycol; silicone; siloxane; dinonyl phenol; and ethylene oxide/propylene oxide block copolymer.

20

25

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☒ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☒ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**